Fyzikálny časopis 20 (1970), No. 2

THE CURRENT EFFICIENCY OF A RADIO-FREQUENCY MASS SPECTROMETER

VIKTOR MARTIŠOVITŠ, Bratislava

The current efficiency of a Bennett-type radio-frequency mass spectrometer as a function of the retarding potential was measured. The disagreement between the experiment and theory observed by several authors is discussed. This discrepancy is explained by the great spread in energy at the ion source. A new experimental method has been used to study this problem and experimental results obtained are shown to agree well with theory.

INTRODUCTION

An important parameter of the mass-spectrometer is its current efficiency characterized by the ratio I/I_0, where I is the collector current and I_0 is the ion current on input of the spectrometer. The following expression has been derived [1, 2, 3] for current efficiency of a Bennett radio-frequency mass spectrometer

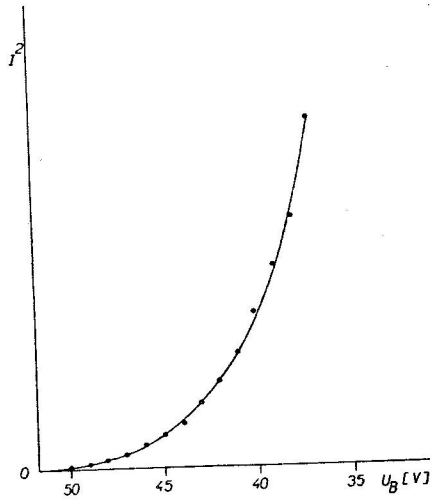

Fig. 1. Current efficiency as a function of the retarding potential.

$$I/I_0 = \frac{\sqrt{2}}{\pi}(1 - K)^{1/2}, \tag{1}$$

where $K = e(U_B - U)/W_m$; e is the elementary charge, U_B is the retarding potential, U is the initial energy of ions and W_m the maximum energy that the ions can obtain in the r. f. field of the analyser. This relation is approximative one and is applicable for K near to 1.

According to relation (1), dependency between I^2 and U_B must be a linear one. This dependency had been experimentally verified by many authors either directly [1, 4] or, from their measurements, it was possible to deduce the form of this dependency [5] indirectly. In all these cases there is an obvious disagreement between experiment and theory. Some authors explained it by a nonhomogeneity of the retarding field, caused by the retarding grid structure.

As the relation (1) is of essential importance for quantitative spectrum evaluation we have been concerned also with its verification.

EXPERIMENT

The Bennett radio-frequency mass spectrometer used in these studies is a 7—5 cycle three-stage instrument and it has been described in [6]. Since a shift of the peak was observed with an increase of U_B, the measurements

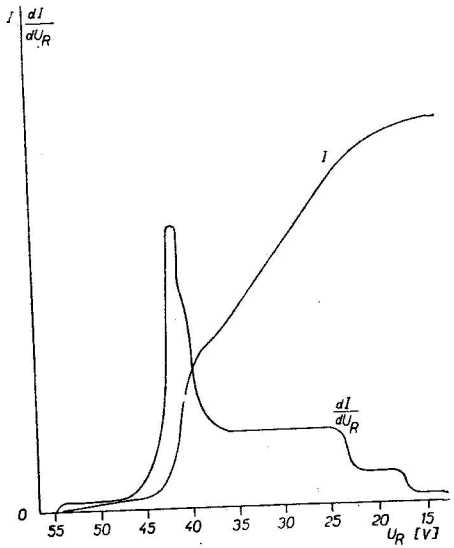

Fig. 2. Retarding characteristic and distribution function of the energy of ions leaving the longitudinal ion source. The radio-frequency signal was switched off and the source was operated at a potential of 43 V positive to the collector.

were made in two ways: at constant frequency of the r. f. field f, or, the frequency was tuned at each value U_B until a maximum in the ion current was observed. For measurement the mass 40 peak ^{40}A was chosen, the accelerating voltage of ions was 100 V, the r. f. voltage possessed the frequency 2.45 MHz and the amplitude 11 V. At a constant f, the dependency of I upon U_B could be approximated by means of two straight lines, similarly as in paper [4]. In the second case the dependency of I upon U_B was approximately a linear one and consequently, the dependency of I^2 upon U_B was represented by a parabola (Fig. 1). Thus, in both cases, the exponent n in the dependency $I \sim (1 - K)^n$ is instead of $\frac{1}{2}$ approximately 1. As the grids in our instrument are dense enough (5 wires per 1 mm with a distance of the grids of 3.5 mm), we assume that this disagreement cannot be explained by a field nonhomogeneity in the region of the retarding grid.

A shift of the peak in the direction to the smaller mass with an increase of U_B suggests a great spread in energy of ions leaving the ion source. This fact was verified by the retarding measurements, as it is obvious from the retarding characteristic and its differentiation in Fig. 2. These measurements were made by means of a kinetic energy barrier formed by the grid, located between the ion source and the mass analyser. If the ion beam, after being emitted from the source, is confronted with the energy barrier, one is able to determine the minimum energy an ion must possess before it may pass

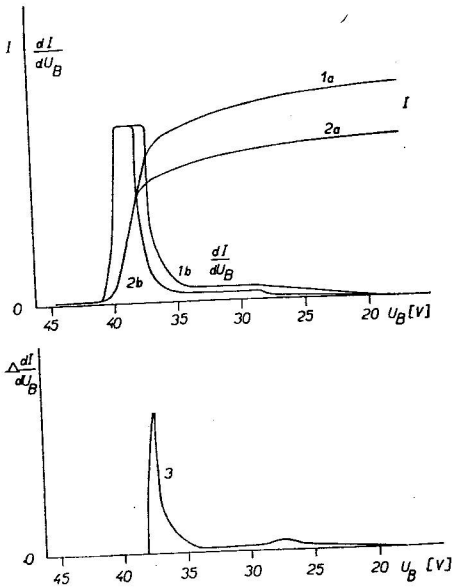

Fig. 3. Principle of application of the retarding potential difference method. The radio-frequency signal was switched off and the ion source was operated at a potencial of 40 V positive to the collector.

on to the analyser. By changes in the retarding potential U_R applied to the grid the distribution in the energy of ions leaving the source can be obtained.

As the radio-frequency signal was switched off during the retarding measurements, ions gained no energy in the analyser and the collector measured a current generated by all ions present in the source. This situation occurs if the potential on the collector attracts ions originating in the source and no decelerating and retarding potentials are present. To ensure this, the source was operated at a potential of 40—43 V positive to the collector.

As the measured spread in the energy of ions reached up to 27 eV, the basic assumption of monoenergeticity of ions entering the analyser, which was used for the derivation of equation (1), was not fulfilled at all. As the current efficiency increases with the initial energy of an ion [see Eq. (1)], an especially important deficiency is a too wide voltage interval over which the distribution function changes, around the cut-off, from a maximum value to zero.

Considering that our longitudinal ion source is constructed similarly as in the papers mentioned above [1, 4, 5], one can suppose that there also occured a similar spread in energy. Considering the fact that by change of the ion source parameters we did not succeed in decreasing the spread in energy of ions, we had to search for another method for the elimination of the influence of the spread. The application of the retarding potential difference method used by Fox and al. [7] in the measurement of the probability of

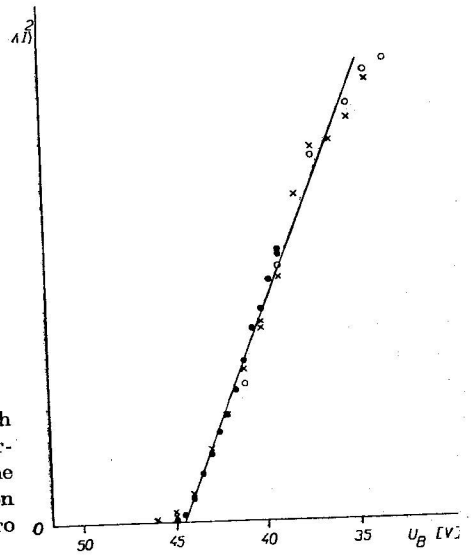

Fig. 4. Variation of current efficiency with retarding potential measured by the retarding potential difference method. The radio-frequency signal was switched on and the ion source was operated at zero potential.

electron ionization proved to be the right one. Even if the measurement according to this method is exacting, its advantage is in the fact that it can be used without any modifications of the spectrometer.

The retarding potential difference method enables to eliminate the difficulties arising from the great spread in the energy of ions being the equivalent of a method using the monoenergetic ion beam. This method utilizes the retarding field which prevents the low energy ions in the distribution to enter the analyser. The increase in the ion current observed when the value of the retarding potential is decreased by ΔV represents the ion current produced by a beam of ions monoenergetic within ΔV. The larger and the smaller values of the two corresponding potential readings determine the maximum and minimum energy of the ions producing the difference in the ion current.

The method was applied as follows: in front of the analyser the potential barrier was formed in the way mentioned above, so that from the initial retarding characteristic (this retarding characteristic was measured by the retarding grid, located between the mass analyser and collector, having a d. c. potential of U_B) only the steepest part remained, belonging to the maximum of the distribution function for the ion energy (see the curve 1a and for the differentiation of the retarding characteristic the curve 1b, Fig. 3). It should be mentioned that the conditions in the ion source differed from those in the case represented in Fig. 2. If the barrier increases by a small value ΔV (in our measurement 1 V) all the ions with the energy within the interval ΔV with the lowest energies (the area between the curves 2b and 1b) drop out of the ion beam, which causes the collector current to decrease by ΔI. The dependence of ΔI upon U_B is the same as the dependence of I on U_B would be if the ion source with the distribution function obtained by subtracting the functions 1b and 2b were used (see curve 3). The width of the curve 3 is max. 4 eV and in the case of necessity it can be narrowed down further by the reduction of ΔV (leading however, to a loss of accuracy of measurement, for ΔI is reduced too). The width of the cut-off interval is now especially favourable when comparing with the situation represented by the curves 1b and 2b.

Having switched the radio-frequency signal on, we measured the dependence of $(\Delta I)^2$ upon U_B at the constant frequency f. Results are presented in Fig. 4. Here the dependence is a linear one, in agreement with equation (1). Dispersion of the measured values at a large ΔI is caused by the fact that the absolute value I varies approximately linearly with $1\text{-}K$ (see the foregoing measurement), but ΔI varies as $(1\text{-}K)^{1/2}$, and thus the relative error increased. In the course of measurements the argon pressure of 1.5×10^{-5} torr was employed in the ion source.

CONCLUSION

The disagreement between the theory of the current efficiency of a Bennett radio-frequency analyser and experiment, observed by several authors, was discussed. It was shown that the reason for this discrepancy was the great spread in the energy of ions entering the analyser. By the application of the retarding potential difference method, it was possible to reduce the influence of the energy spread and the experimental results obtained were shown to agree well with the theory. Similar results were obtained when we used a transverse ion source with low energy spread in the ion beam. In such a case no shift of the peak, at an increase of U_B, was observed.

REFERENCES

[1] Dekleva J., Ribarič M., Rev. Sci. Instr. *28* (1957), 365.
[2] Ворсин А. Н., Доильницын Е. Ф., Трубецкой А. И., Щербакова М. Я., *Радиочастотный масс-спектрометр*. Изд. Ак. наук СССР, Москва 1959.
[3] Кучков Е. М., Ж. Тех. Физ. *30* (1960), 568.
[4] Доильницын Е. Ф., Бюл. Ак. наук СССР, сер. физ. 1959, № 9, 31.
[5] Ryan K. R., Green J. H., J. Sci. Instrum. *42* (1965), 455.
[6] Martišovitš V., Mat. fyz. čas. SAV *13* (1963), 72.
[7] Fox R. E., Hickam W. M., Kjeldaas T., Grove D. J., Phys. Rev. *84* (1951), 859.

Received December 19th, 1968

Katedra experimentálnej fyziky
Prírodovedeckej fakulty UK,
Bratislava